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Structural materials in the energy context

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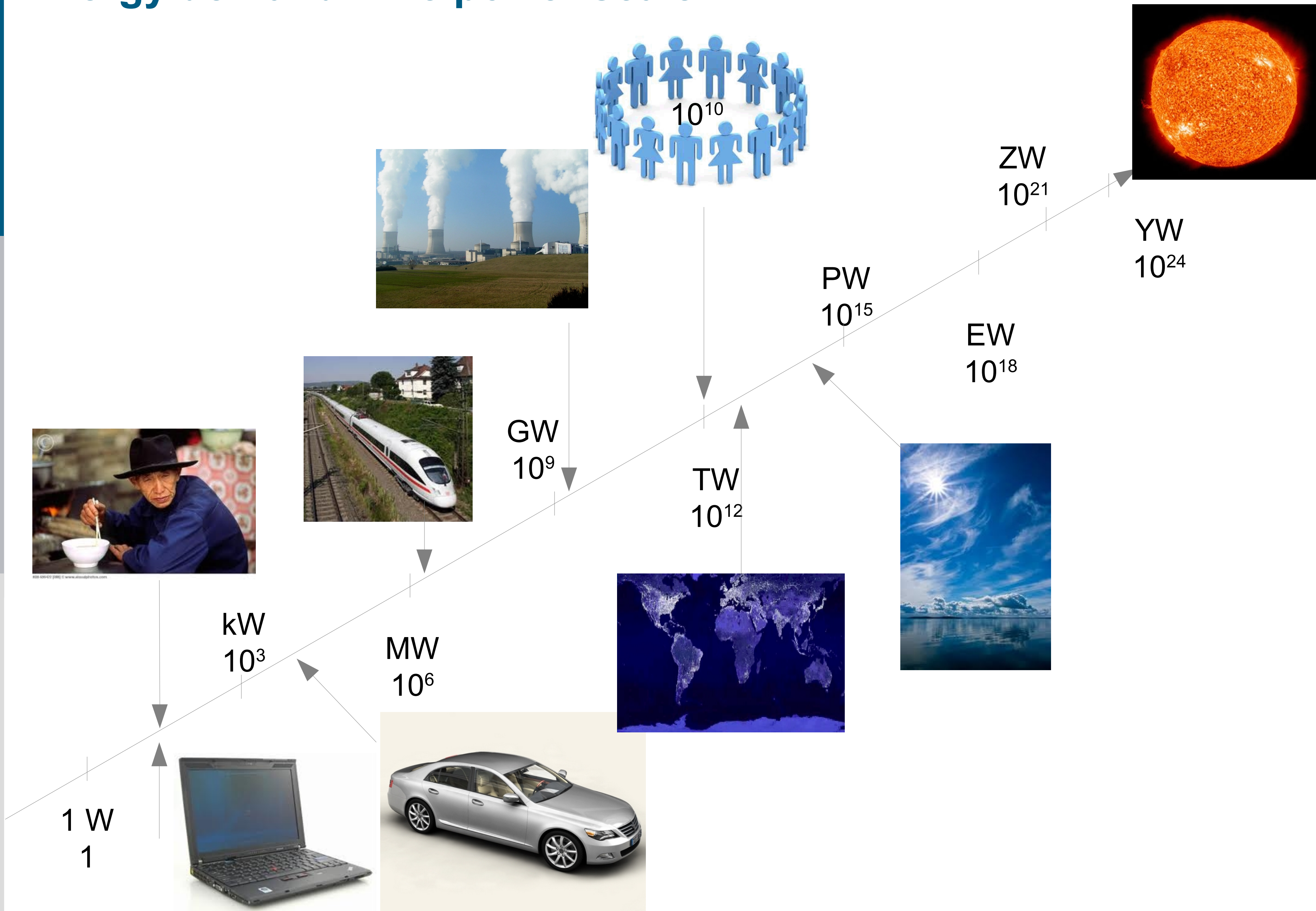
German-Georgian Science Bridge ,Tbilisi, Juli 8th 2014

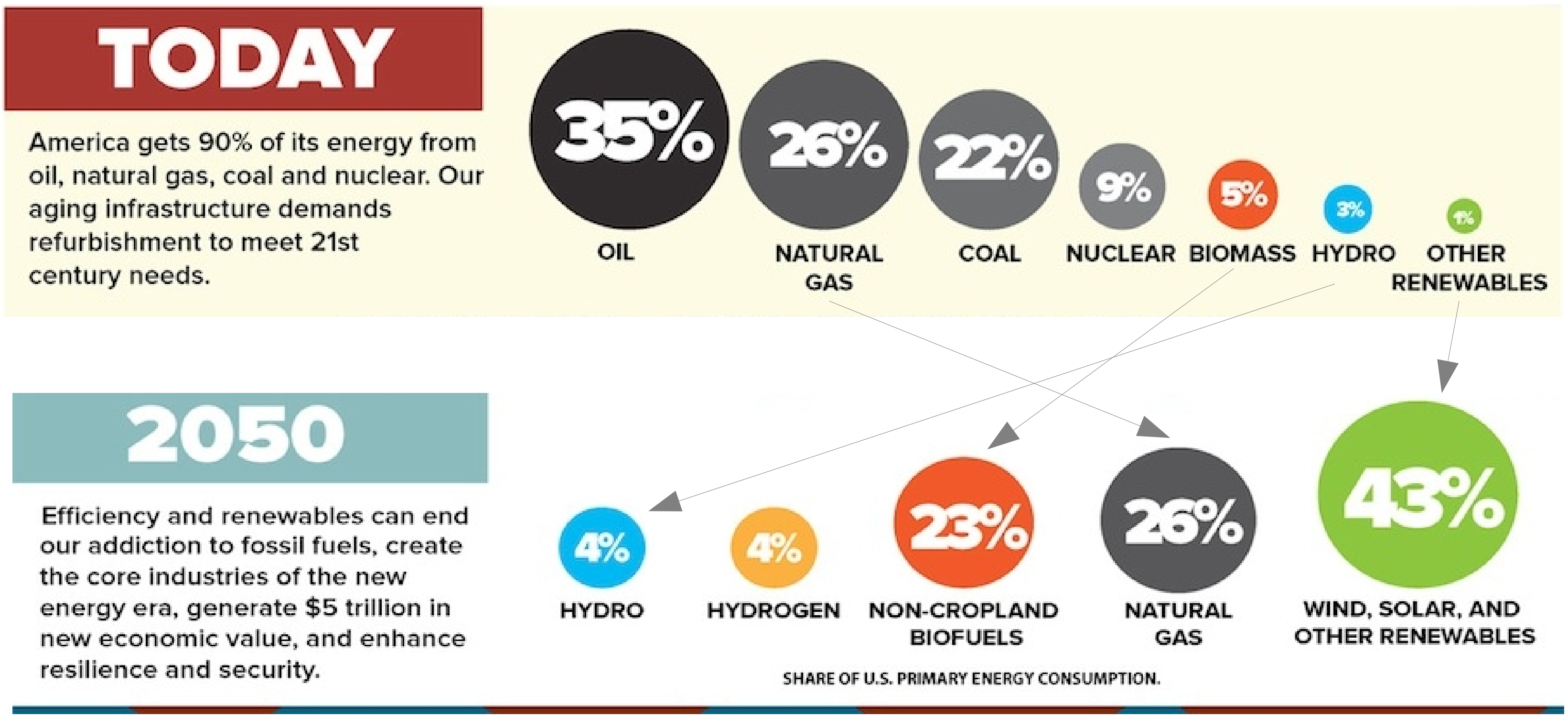
Energy demand: The power scale



Energy offer: fossile fuels

		Proven reserves	Ressources
		40-80 years	50-150 years
		60-180 years	200-600 years
		>200 years	>2000 years
	Uranium:	~50 years	~250 years

Goals / USA



Could save $\$5.10^{12}$, support a 160% increase in economy, and 0 fossile energy

rmi.org

How? One answer: no unique technology

NB: US GDP = 15.10^{12} $

The goals / European Union Roadmap 2050

80% less CO_2 emission

1990 → 2050

50% less energy consumption

No specific scenario is imposed

Priorities

Efficient use of resources at all levels, including energy management in buildings,

Development and integration of renewables and biofuels in the distribution grids,

Improved management of waste, in particular of carbon,

Electrification of transportation,

Development of next generation of ~~fission and~~ fusion power plants.

Link with information technologies: low energy devices and better waste heat management

Fundamentally, energy problems are extremely often materials problems

Notable exception: grid management!

Energy materials

Structural materials

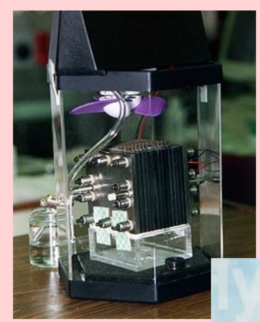
Buildings (concrete 1 MJ/kg, steel 25 MJ/kg, polymers insulators, reactor walls for fusion, ...)
~5% ww CO_2 ~5% ww energy
Materials for transportation (lightweight alloys, high strength turbine blades)

"*The battle against climate change must be won in cities*", P. Löscher, CEO Siemens

Energy transportation

Copper wires vs. High-T_c superconductors
Pipelines, ...

"Active" energy materials



"Sources": photovoltaics, oil & gas, **clathrates**

Storage: batteries, **hydrogen storage**

Savings/Recovery: catalysts, **thermoelectrics**

Conversion: fuel-cells, magnetocalorics

Structural materials – an outdated topic?

at least in basic science, structural materials are often:

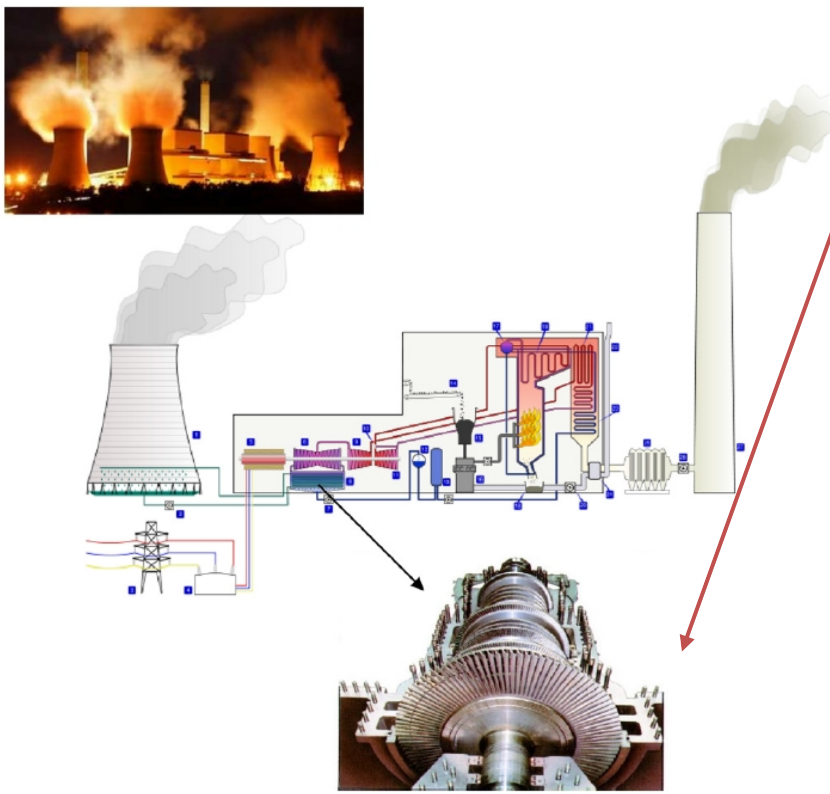
- considered dirty
- considered old-fashioned (all problems solved)
- perceived as being „low-technology“

Dirty? Well … certainly very complex systems, e.g.:

- Al alloy AA7075 Al, Zn, Mg, Cu, Si, Fe, Mn and so on
- steel X10CrNiMoV12-2-2 Fe, C, Cr, Ni, Mo, Mn, V, Si
- glass-fibre reinforced aluminium Al alloy + glass fibre + sub-structure

Structural materials – an outdated topic?

Old-fashioned and low technology?



turbine technology is essential for energy efficieny, key factors:

- fatigue
- temperature stability
- corrosion resistance

new materials required
as well as advanced material characterization

D. Driver, Energy Policy 36 (2008) 4302

Structural materials – an outdated topic?

Old-fashioned and low technology?

Porsche 911, picture by O. Kurmis

every 10% decrease in weight yields ~ 7% in fuel economy

motorized vehicles consume about 20% of the world‘s energy supply (and 80% of this energy is used by road vehicles)

need for new lightweight materials and new joining technologies

Structural materials – an outdated topic?

Old-fashioned and low technology?

Radioactive waste bin, picture by Prolineserver

for nuclear waste disposal radioactive waste (or isotopes) are embedded in a container or solid state matrix

as safe storage for centuries is required, key problems are:

- susceptibility to radiation damage
- corrosion resistance

↓

new materials and advanced characterization to mimic storage effects

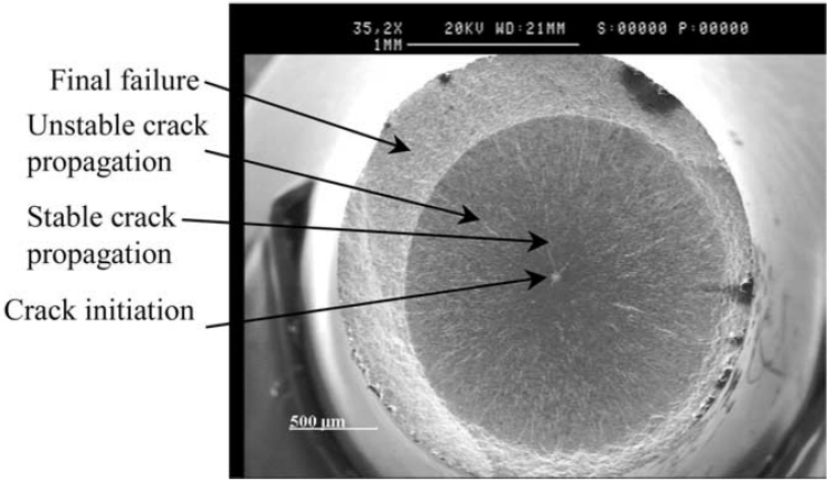
Structural materials – an outdated topic?

Not old-fashioned, but in vogue!
Not low technology, but complex/high technology!

In the following two examples:

Eu based zirconates

VHCF steel for turbine blades



Pyrochlores as nuclear waste hosts

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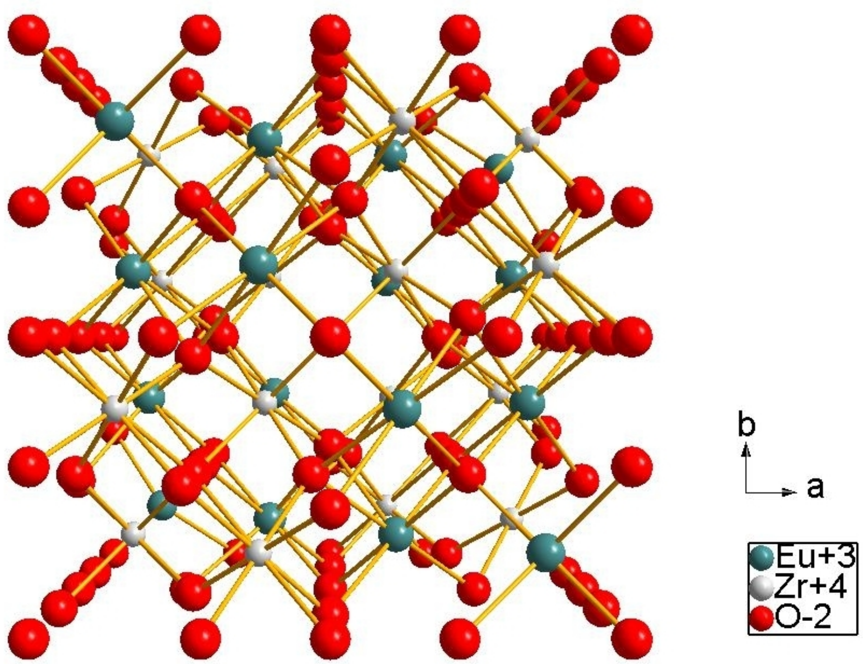
Coll. IEK-4 S. Finkeldei, D. Bosbach

during the last 5 decades: 1400 tons of Pu, Np, Am and Cm have accumulated → proliferation and disposal issues

solution: use host matrix, e.g. pyrochlore $A_2B_2O_7$

radioactive Am can „populate“ A-site

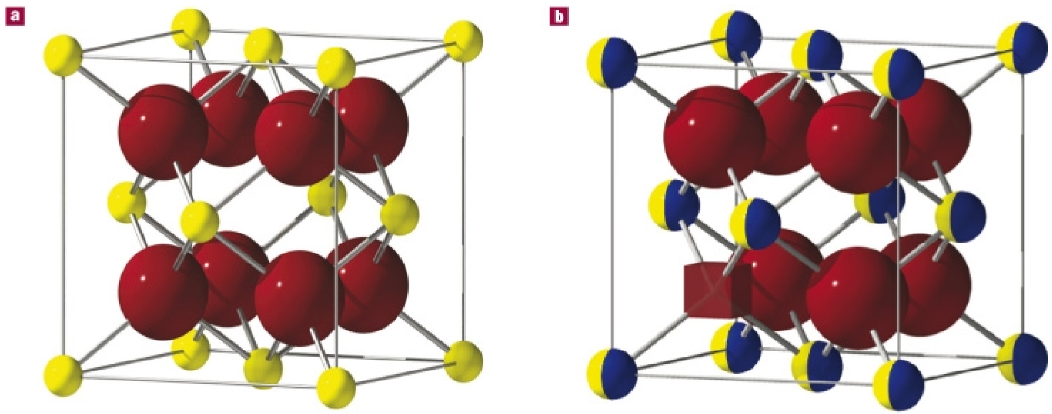


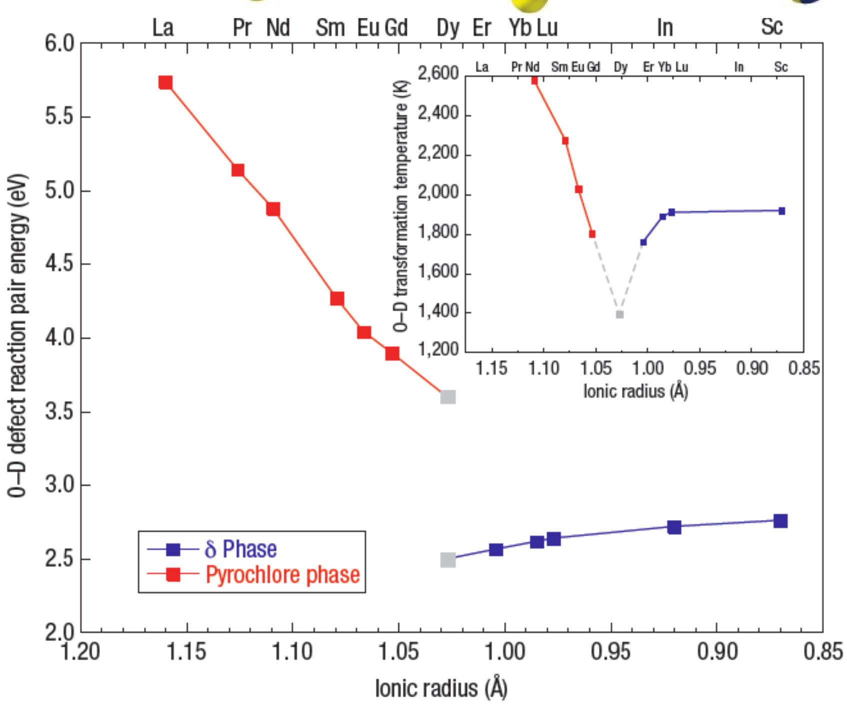
major questions:
- chemical resistance
- amorphization resistance

Eu as proxy of Am

Pyrochlores as nuclear waste hosts

in zirconates: superior amorphization resistance due to order-disorder transition, i.e. pyrochlore to defect-fluorite





Sickafus et al., Nat. Mater. 6 (2007) 217.

disorder is accomodated easily (low defect pair formation energy)

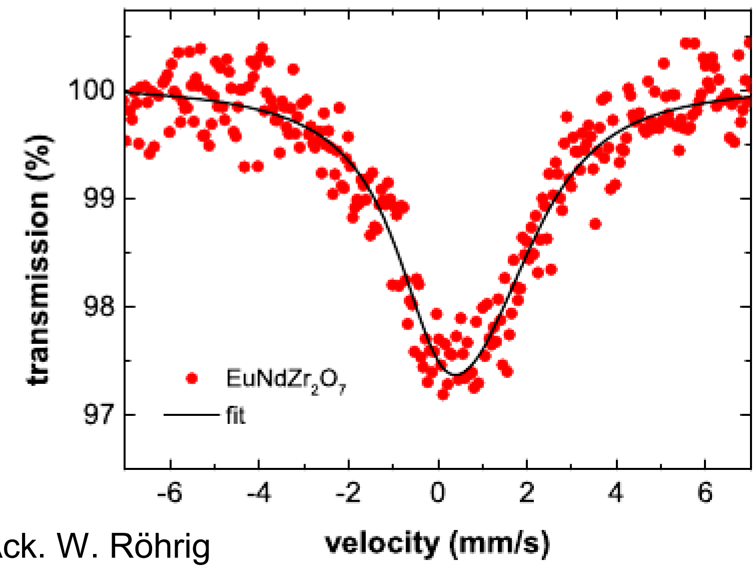
↓

high amorphization resistance

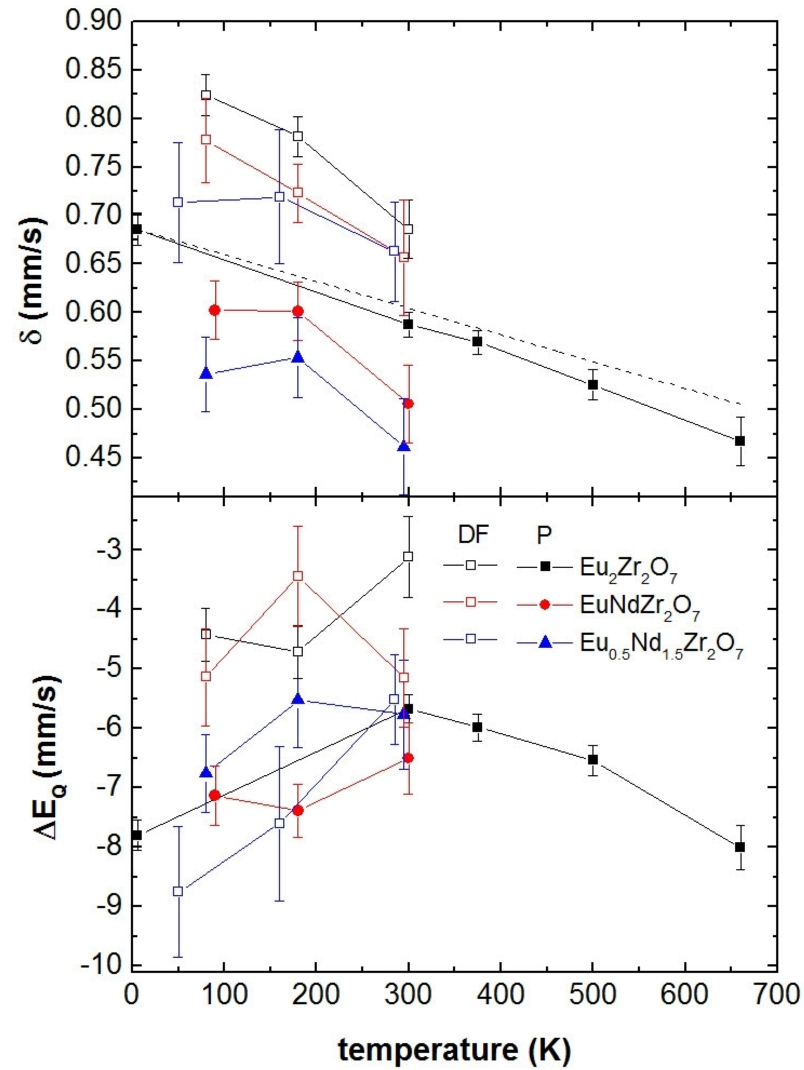
What about local structure and vibrational properties concerning this transition?

Pyrochlores - Mößbauer spectroscopy

accessing Eu locally using the 21.6 keV nuclear transition in ^{151}Eu and hyperfine interactions



Ack. W. Röhrig



to some extent the order-disorder transition is reflected in ΔE_Q

more important: isomer shift δ can be used to estimate the amount of pyrochlore vs. defect-fluorite

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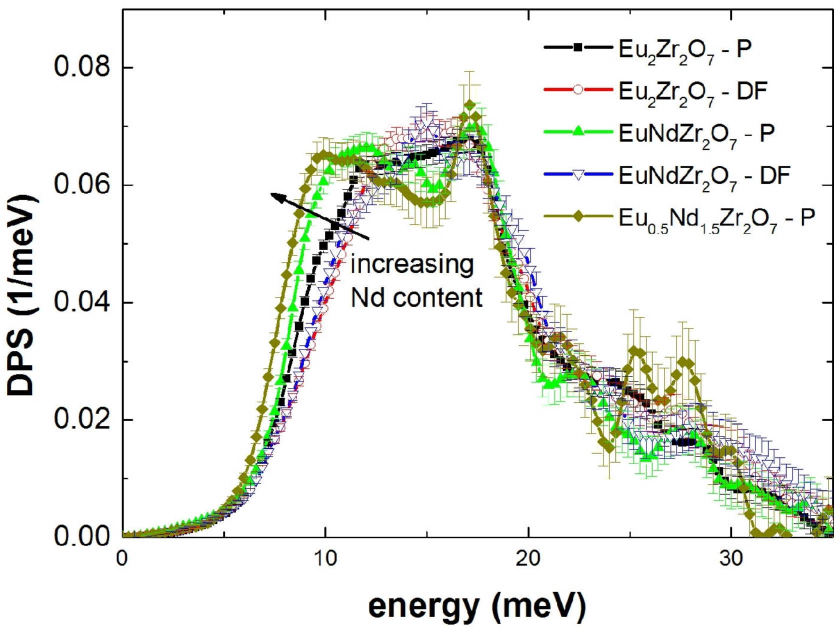
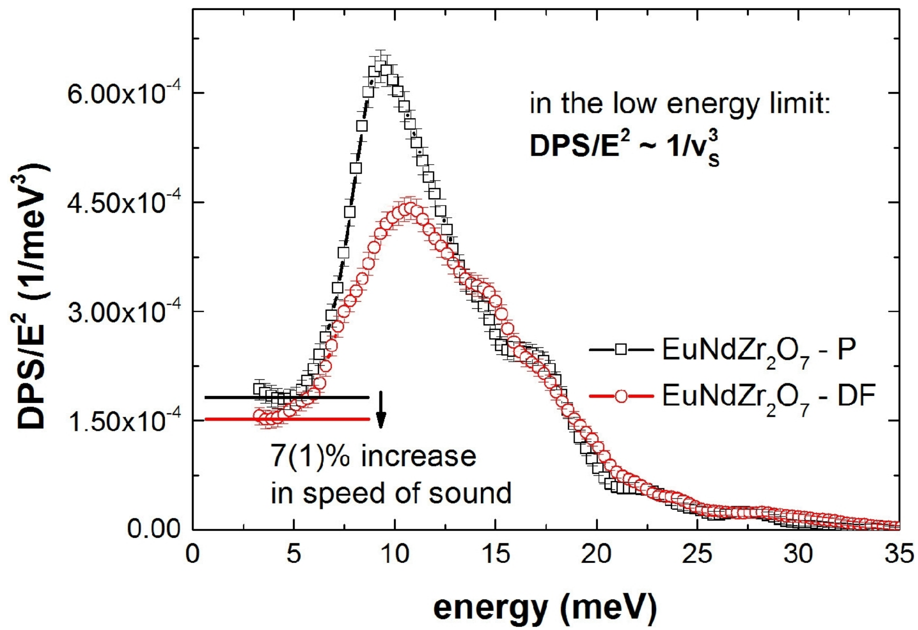
Pyrochlores – Inelastic Scattering I

nuclear inelastic scattering for Eu-specific phonons





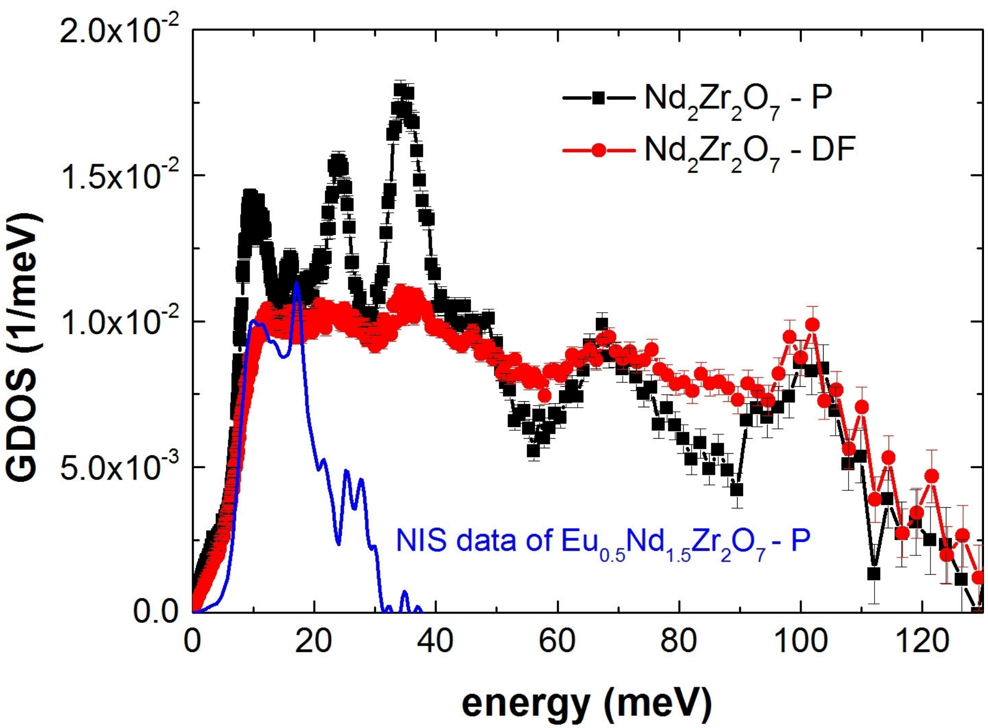
Ack. D. Bessas, ID18 ESRF

- pyrochlore softens upon Eu→Nd substitution (*a* increases)
- speed of sound increases in defect-fluorite

Pyrochlores – Inelastic Scattering II

inelastic neutron scattering using FOCUS @ SINQ

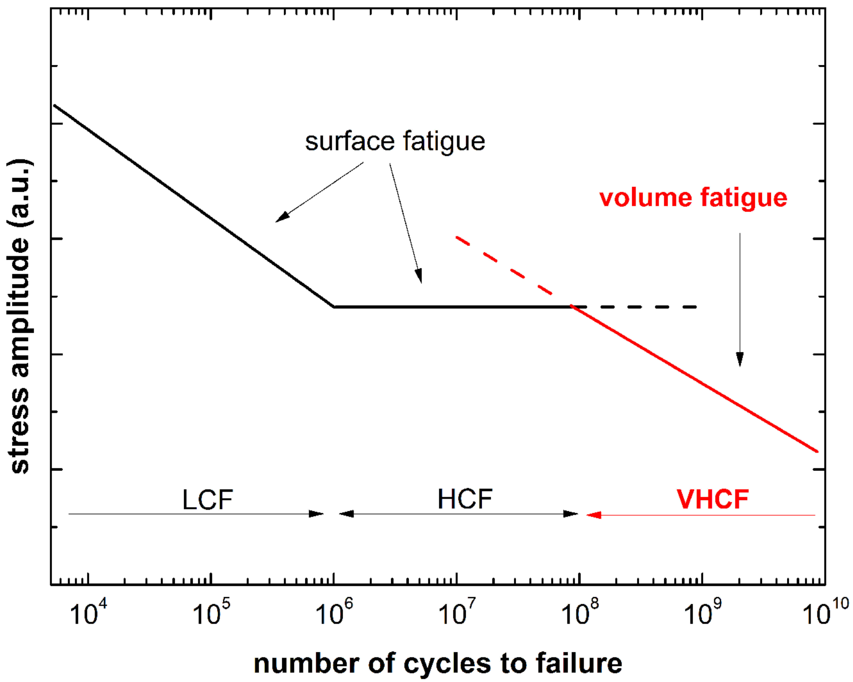
Ack. F. Juranyi

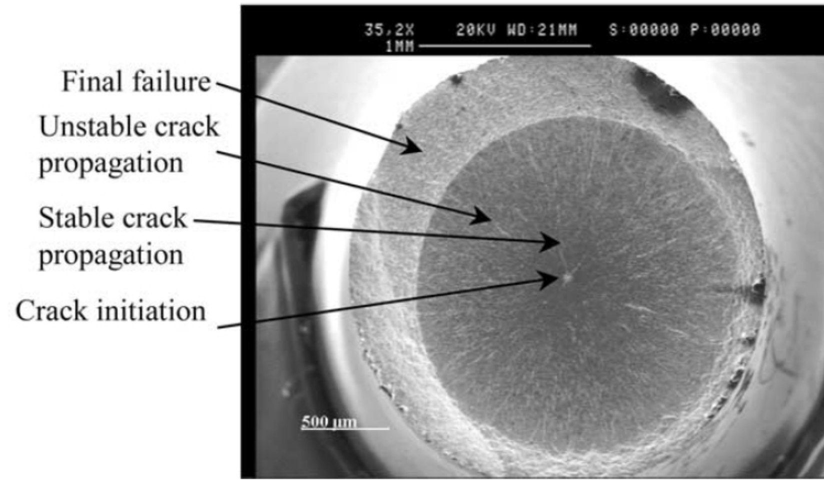


order-disorder transition manifests primarily in the Zr-O sublattice

Early stages of VCHF in steel

Coll. IEK-2 T. Beck, L. Singheiser





Q.Y. Wang et al., Int. J. Fatigue 24 (2002) 1269.

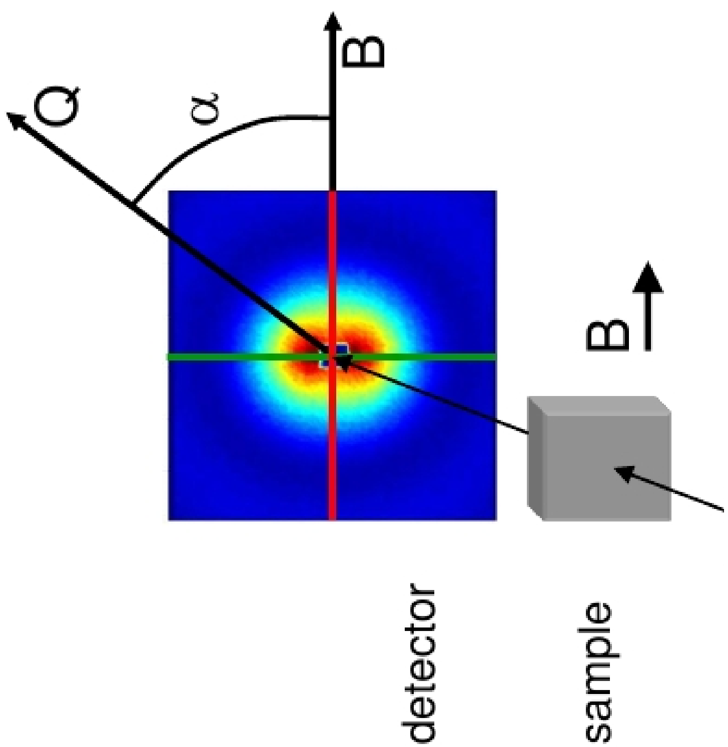
(very) high fatigue resistance → long service life → less maintenance → ligher efficiency

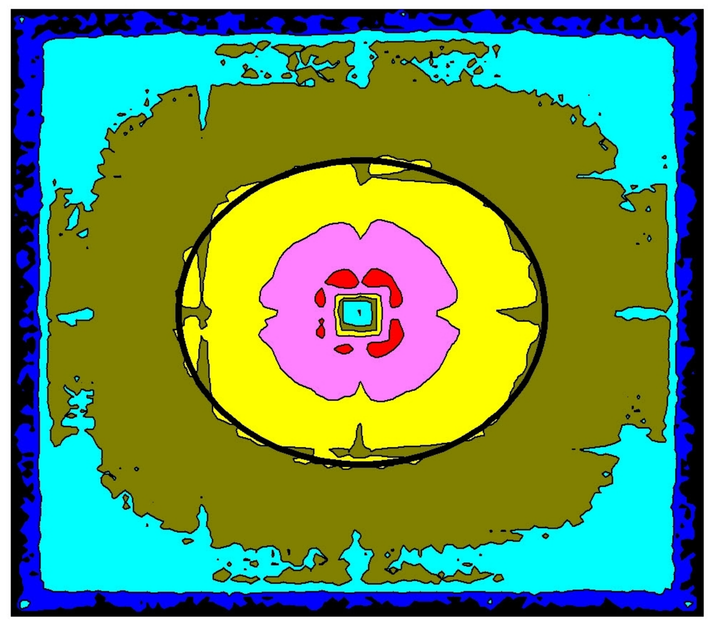
1. What happens during most of the material lifetime?
2. When do cracks form?

Early stages of VCHF in steel - SANS

X10CrNiMoV12-2-2: 12 $\%_{wt}$ Cr, 2.5 $\%_{wt}$ Ni and 1.75 $\%_{wt}$ Mo

Small Angle Neutron Scattering (SANS) using KWS-1 @ MLZ





← nuclear + magnetic scattering

↑ nuclear scattering

Early stages of VCHF in steel - SANS

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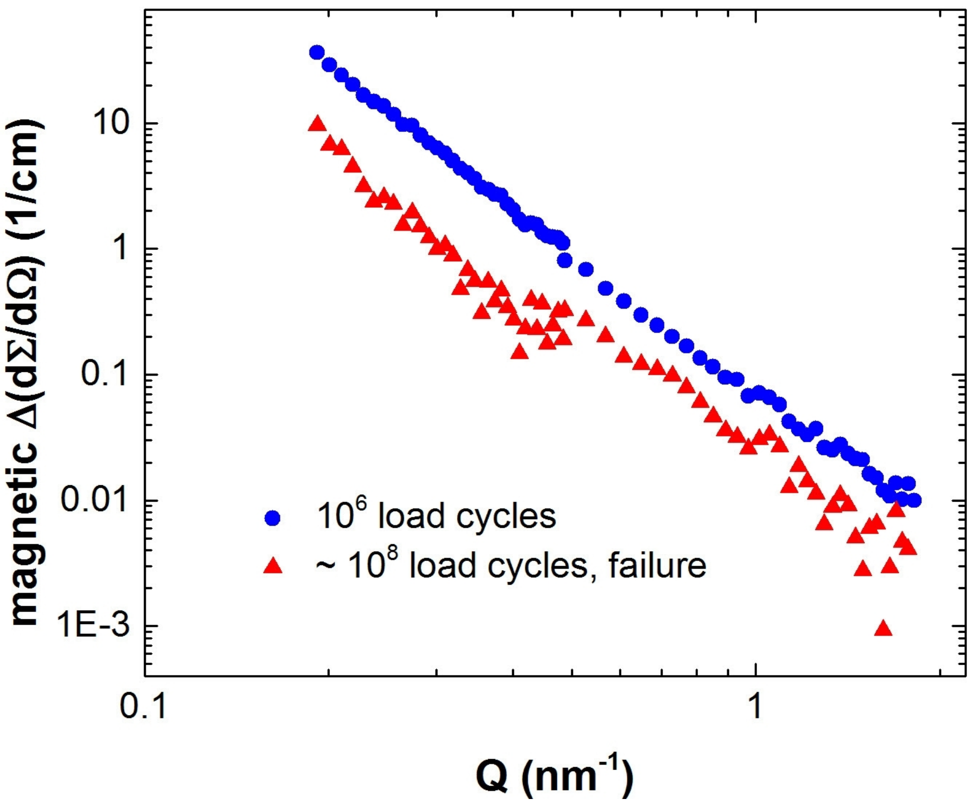
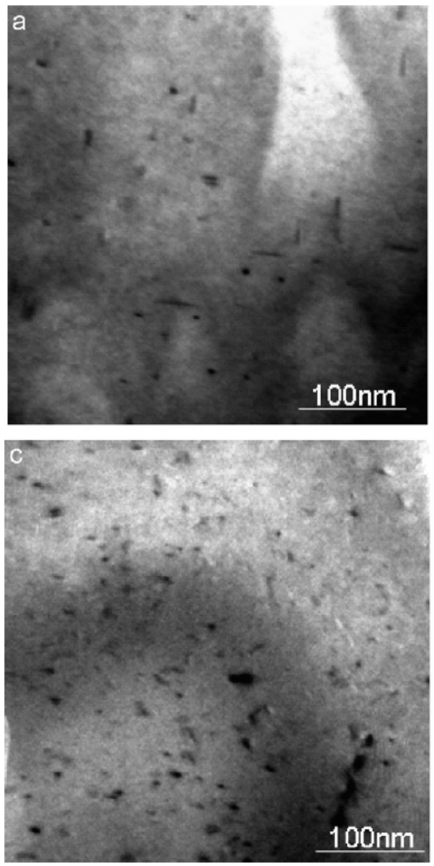


magnetic difference scattering with respect to pristine sample:

- signal measurable
- interpretation work in progress

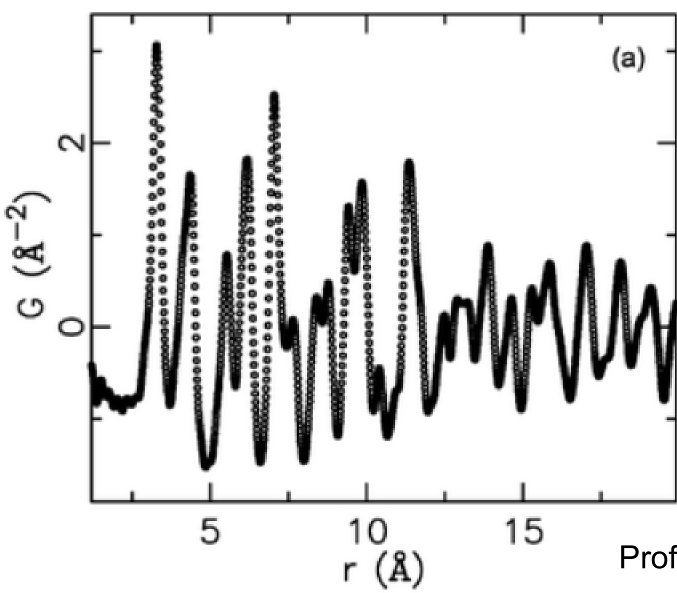
Structural materials – a scattering outlook I

small clusters formed at intial stages of processing may have strong impact on final properties



Chang et al., Ultramicroscopy 109 (2009)

good vs. bad microstructure in Al-Mg-Si due to different early stages (small clusters) but 3DAP, SANS, TEM … failed!

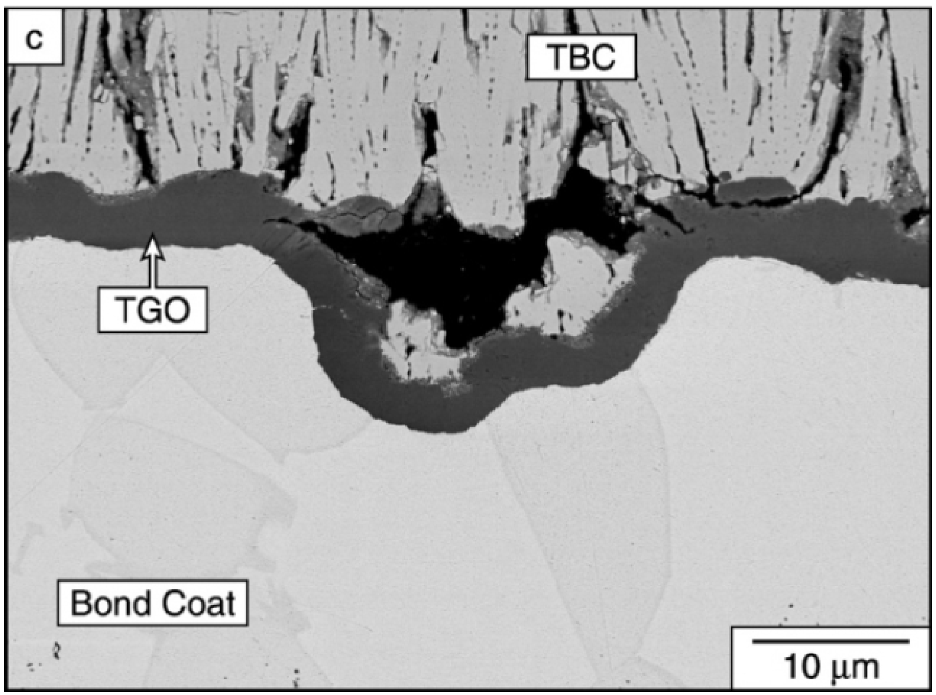


use total scattering approach!

Proffen, J. Mater Chem 19 (2009) 5078

Structural materials – a scattering outlook II

for coating technologies, e.g. thermal barrier coatings, neutron reflectometry may provide major insights



playground:
- interfacial structure
- fracture mechanisms
- process control

Evans et al., Prog. Mater. Sci. 46 (2001) 505.

Summary

- structural materials constitute one of the major problems of energy

- valuable insight can be obtained using „basic“ solid state physics techniques

- there is much more to do